Interactions of Waves and River Plume and their Effects on Sediment Transport at River Mouth

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LONG-TERM GOALS

To develop a robust coastal/nearshore modeling system for inlet hydrodynamics, sediment deposition/resuspension, river plume processes and the resulting morphodynamics in a highly dynamic environment dominated by strong tidal flows and waves.

OBJECTIVES

- To study the interactions of tidal flow, waves and complex bathymetry at New River Inlet, NC using NearCoM-TVD and field data observed during the recent field campaign through close collaboration with other researchers.

- To study how a spatially/temporally varying bottom friction parameterization due to wave-current interactions, seabed dynamics (bedforms; sheet flows) can affect the hydrodynamics, sediment transport and the resulting morphodynamics of a tidal inlet.

- To investigate the relationship/correlations between the flow variables computed from the numerical model results and remotely-sensed signatures.

SIGNIFICANCE

Studying the hydrodynamics, sediment transport and the resulting morphodynamics of inlets and river mouths is critical to many scientific and engineering applications. The interaction between the hydrodynamics and complex bathymetry can produce highly heterogeneous and locally intense flows. Moreover, the morphological evolution also becomes much more dynamic closer to an inlet. These two factors cause concerns over navigation safety especially in areas where routine surveys are not possible. Through significantly improved remote sensing technology, data on the surface flow features and limited information on the bottom bathymetry can be obtained. However, a complete prediction on the detailed hydrodynamics, bottom bathymetry and morphodynamics still relies on numerical modeling. On the other hand, it is also unclear if existing wave-averaged coastal modeling systems are sufficiently robust to provide the critical link (interpolation) between the remote-sensing data and the ground-truth data. The main challenges appear to be due to several key intra-wave and bottom boundary layer processes that are not directly resolved in typical coastal modeling systems.

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In the past decade, there have been significant amount of research efforts devoted to improve the wave-current coupling in a wave-averaged coastal modeling system (e.g., Putrevu & Svendsen 1999; Mellor 2005; Kumar et al. 2011). The numerical model, NearCoM, adopted in the proposed study is due to one of such efforts supported by NOPP and Office of Naval Research (Shi et al. 2003, 2011). On the other hand, processes that occur in the bottom boundary layer, such as the enhanced roughness due to waves and bedforms, also play critical roles in determining the bottom friction. Typical coastal modeling systems are not designed to resolve processes occur close to the seabed, such as the centimeter-scale wave boundary layer. Hence, an appropriate bottom friction formulation, which parameterizes the key nearbed and seabed processes, need to be implemented. From the experiences learned from many large-scale coastal modeling studies, it is clear that bottom friction is one of the most sensitive parameters in determining the resulting flow pattern and intensity. Hence, there is a critical need to improve the existing bottom friction parameterization with more physical-based insights from small-scale studies. Recent field experiments at New River Inlet, NC (RIVET I) provide comprehensive data on hydrodynamic, sediment transport and bathymetry change via in-situ and remote-sensing measurements at both large and small scales. Results disseminated by many researchers involved in RIVET I efforts allow detailed validation of the existing coastal modeling systems with a longterm goal to bridge the remotely-sensed signatures with water column and seabed processes using numerical models. In this report, we discuss our prelimnary efforts to validate NearCoM-TVD with field data and environmental parameters made available by many researchers through RIVET I collaborative research effort.

APPROACH

A new version of the Nearshore Community Model System (NearCoM-TVD) is utilized in this study to investigate hydrodynamics, sediment transport and morphological evolution of New River Inlet, NC. NearCoM-TVD integrates the wave model SWAN (Booij et al., 1999) and the quasi-3D nearshore circulation model SHORECIRC (Svendsen et al. 2004). The quasi-3D circulation model incorporates the effect of wave on the vertical structure of current based on the theory of Svendsen & Putrevu (1994). There is very limited freshwater input at New River Inlet and the flow is assumed to be well-mixed in this study. Hence, we adopt the depth-integrated circulation model. The key advantage in this assumption is that the depth-integrated formulation is computationally efficient that allows us to simulate very large domain with long duration (e.g., the entire field experiment period is about one month) such that investigation on morphological change can be carried out (several month without using morphology factor; or a storm event). Comparing to the original NearCoM, there are several new capabilities of NearCoM-TVD that we had implemented in the past two years in order to use it for tidal inlet applications. These new features are summarize as follow: a) The coupling of SHORECIRC and SWAN in a curvilinear coordinate system allows capturing the important feature of nonlinear wave-current interaction in the nearshore, and in the meantime carrying out large-scale simulation with a computational domain that covers both the continental shelf and the estuary. Hence, realistic tidal forcing in the study area can be simulated. b) The numerical model is parallelized using MPI and it is computationally efficient such that processes involve timescales of weeks to months can be simulated. c) Implementation of sediment transport and morphological evolution, including morphology factor for long-term (year) morphodynamic simulation.

WORK COMPLETED

In early 2012, we carried out simulations and made simulation results available to field experimentalists of RIVET project to evaluate the phase lag between velocity and surface elevation in

the inlet (Elgar/Raubenheimer; Geyer/ Traykovski) and the timing of drifter release (Feddersen/Guza). We also carried out diagnostic simulations on the tidally-averaged residual flow structure around the inlet and investigated the role of waves and bottom friction in enhancing the flow intensity (Chen et al. 2012). A webpage is also established since this March to disseminate model results: http://www.coastal.udel.edu/~jialin/NewRiver.htm

Since this summer, we carried out detailed model-data comparions on flow velocity and wave height distribution during the month of May 2012 when the field experiment at New River Inlet was carried out. So far, we have collaobrated with Elgar/Raubenheimer's team to validate modeled flow velocity with measured data at about 25 sensors throughout the inlet channels and nearshore region. We also collaborated with Geyer/Traykovski's team on mode-data comparison on two sensors located in the old and new channel where significant bedform migration was observed. We also provided detailed model results to Guza/Feddersen's group to carry out drifter prediction and comparison with measured drifter trajectories. The highlights of our finding will be discussed in the next section. Recently, we started to collaborate with McNinch's group to investigate the most suitable flow parameters computed by the numerical model that best correlate with data measured from their RIOS (Radar Inlet Observing System). In the near future, we also plan to carry out model prediction on morphological change in comparison with their weekly bathymetry data.

RESULTS

For the model simulation results presented here, we utilized bathymetry provided by Dr. McNinch (USACE) surveyed on May 1~2, 2012. The entire model domain extends from the edge of the continental shelf to the estuary. A close up view near the inlet is shown in Figure 1. A deeper (new) channel (5~10 meter in depth) located in the lower side of the inlet can be clearly seen while the depth in the upper side of the inlet is shallow (old channel). A curvilinear mesh is adopted with coarse resolution offshore and fine resolution in the nearshore region and around the mouth of the inlet (minimum mesh size is 10 m). Model results shown here are for May 1st~20th. The tidal boundary condition is implemented via surface elevation data from the tidal database of large-scale circulation model ADCIRC (see Figure 2a). The offshore boundary condition in SWAN is given as a JONSWAP distribution using measured significant wave height and wave angle from direction Waverider ID 190 (Figure 2b and 2c). In this report, we present detailed flow field simulated by the numerical model on May 16, which is of neap tide and moderate wave energy (see shadowed area in Figure 2). In general, tidal elevation is larger during the first 10 days of the month with low wave energy while waves become more energetic during the last 10 days of the month (maximum H_s exceeds 2.5 m, not shown here).

Figure 3 (a) and (b) shows the simulated instantaneous flow velocity field during maximum flood and maximum ebb on May 16 when the offshore significant wave height is of H_s=1.2 m. In general, the intensity of the flow through the inlet is quite large. Specifically, flow is stronger in the new channel due to smaller bottom friction (larger flow depth) and the peak magnitude can exceed 1 m/s during ebb. The ebb tidal jet is diverted into three components while the central jet (the one passes the old channel) remains to be the strongest (see Figure 3 (b)). Around the outer edge of the ebb jet, vortex structures can be clearly seen, which are due to complicated interaction of waves, currents and bathymetry change. It is also noted that during flood, a more organized flow toward the inlet can be observed in the shallow region near the two side entrances (see Figure 3 (a)). On the other hand, during ebb the outflow is less organized in the two side entrances. Due to these asymmetries, tidally-averaged residual

flow is ebb directed in the channels and flood directed near the two sides of the inlet. These asymmetries may have significant implication to sediment transport.

Figure 4 shows modeled velocity in comparison with measured flow velocity at Sensor #56, which is located at the mouth of the inlet in the old channel (see Figure 1). Measured flow velocity is provided by Drs. Elgar and Raubenheimer (WHOI). The numerical model is able to predict the phase and the magnitude of the velocity through the channel over the entire 20 days simulated. It is clear that flow at this location is dominated by tidal modulations due to strong current through the inlet. However, at Sensor #78, which is located more offshore at a water depth of around 6 m, the flow intensity is much weaker and wave-induced currents become more dominant (see Figure 5) due to strong transition of wave radiation stress (not shown). In general, there is a sharp transition of the intensity and pattern of the flow when moving away from the inlet due to diminishing tidal jet and enhanced wave-current interaction. It should be also noted that modeled tidal current intensity through the inlet is sensitive to the bottom friction coefficient used (the phase is however not sensitive). An increase of bottom friction coefficient from typical value used for estuary (~0.003) up to that for nearshore (~0.01), the maximum ebb current decreases by 50%. Difference in tidal averaged residual flow can be up to factor two. We are currently validating the predicted wave field with in-situ data and remotely sensed data. More detailed investigation on the relative importance of tidal forcing, waves and bottom bathymetry in determining the resulting flow field will be carried out through numerical experiments and idealized tidal inlet study.

IMPACT/APPLICATIONS

Our coastal modeling effort using NearCoM-TVD at New River Inlet compliment other modeling efforts in this DRI utilizing Delft3D and wave-resolving Boussinesq wave models. Model results also help other researchers, who focus on in-situ measurements and remote sensing, to better interpret the wave-current hydrodynamics and surface features. Through this DRI, the development of NearCoM-TVD is significantly enhanced with abundant data measured by other researchers through detailed model-data comparison.
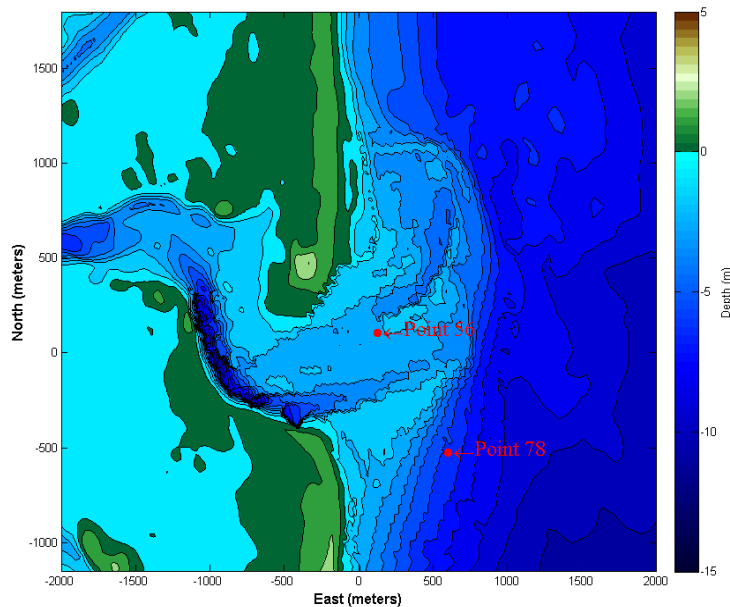

Figure 1: Bathymetry of New River Inlet with two sensor locations (#56, #78) discussed in this report. Bathymetry data is provided by Dr. McNinch (USACE).
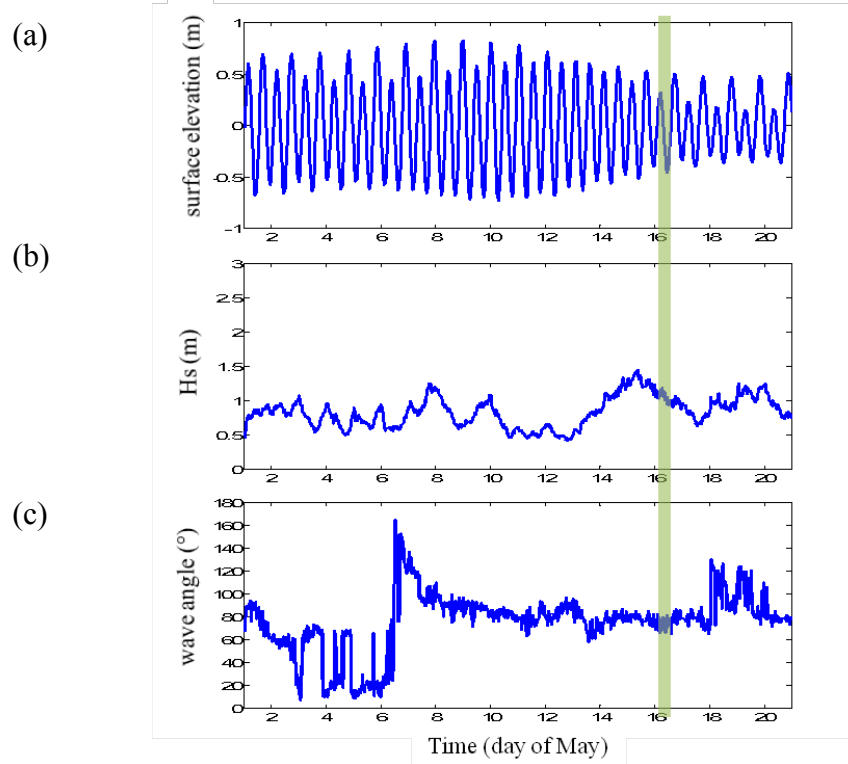
Figure 2: (a) Surface (tidal) elevation specified at the offshore boundary using the tidal data base provided by ADCIRC (http://adcirc.org); (b) significant wave height and (c) wave direction during May 1ˢᵗ to 20ᵗʰ from directional Waverider ID190 (see http://www.frf.usace.army.mil/waverdr190/realtime.shtml)
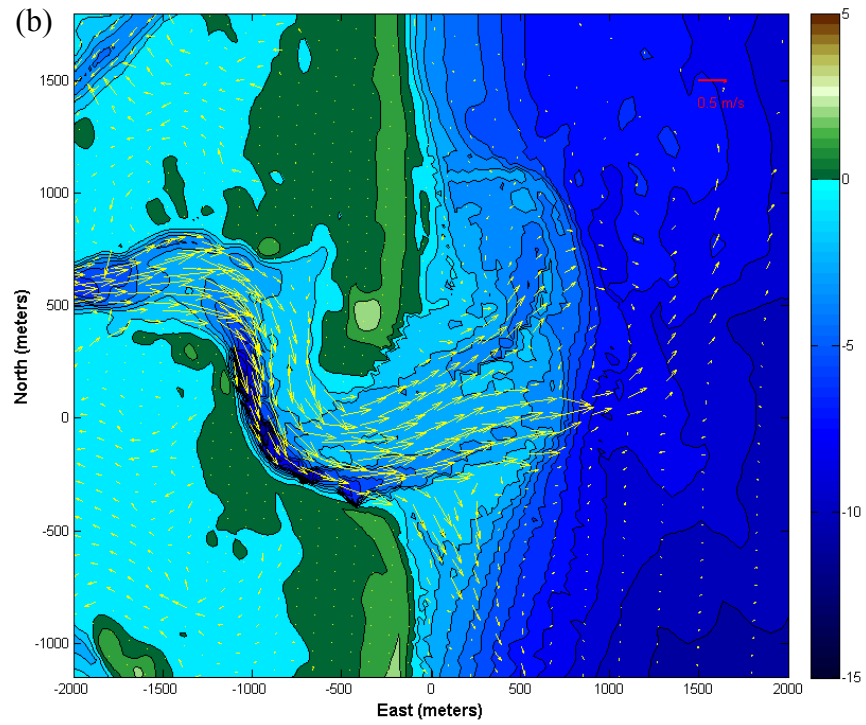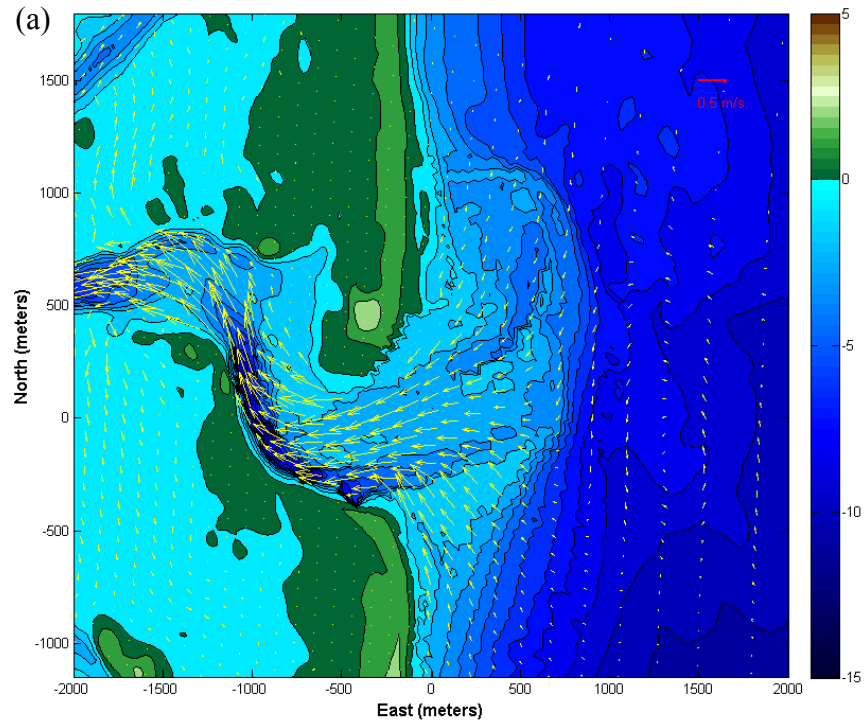
Figure 3: Instantaneous flow velocity during (a) flood and (b) ebb on May 16. This is a day with moderate wave energy during neap tide.
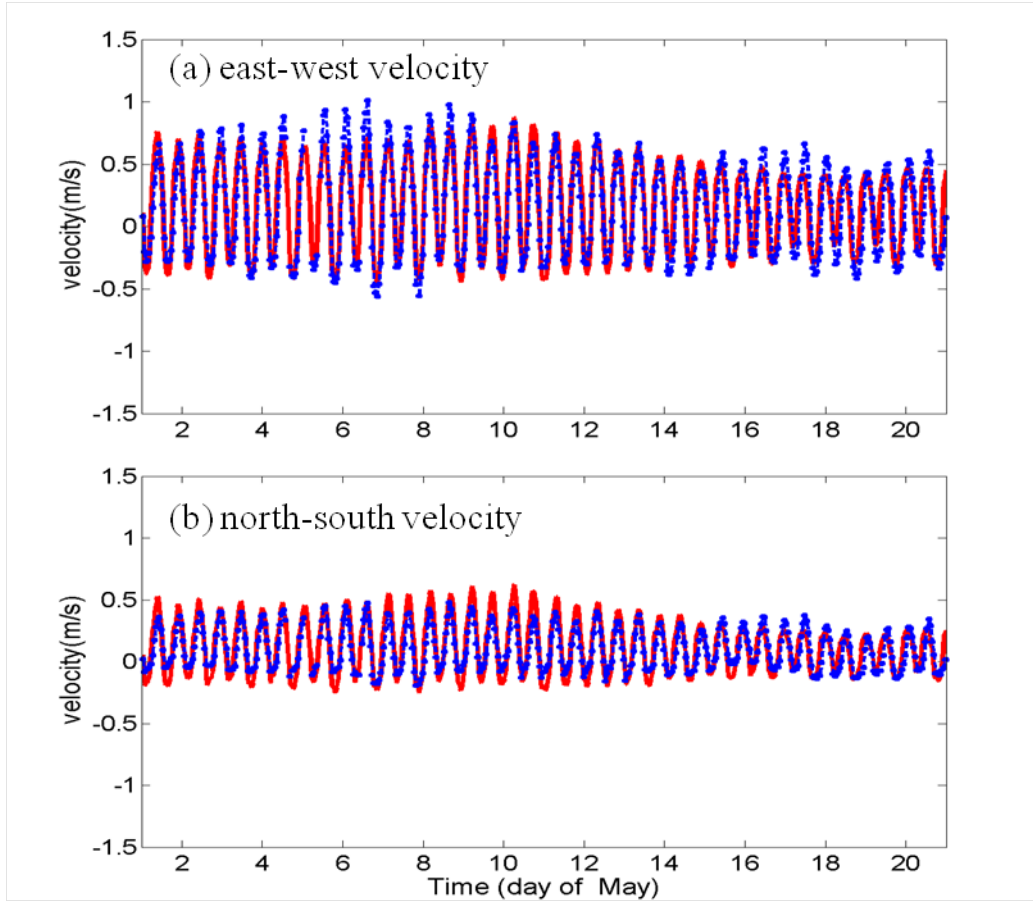
Figure 4: Comparions of time series of flow velocity in the east-west (a) and north-south (b) directions between the numerical model results (red curves) and measured data (blue dots) at Sensor #56, which is located in the old channel (see Figure 1). Flow velocity is dominated by tidal flow modulation through the inlet. Field data is provided in collaboration by S. Elgar and B. Raubenheimer (WHOI).
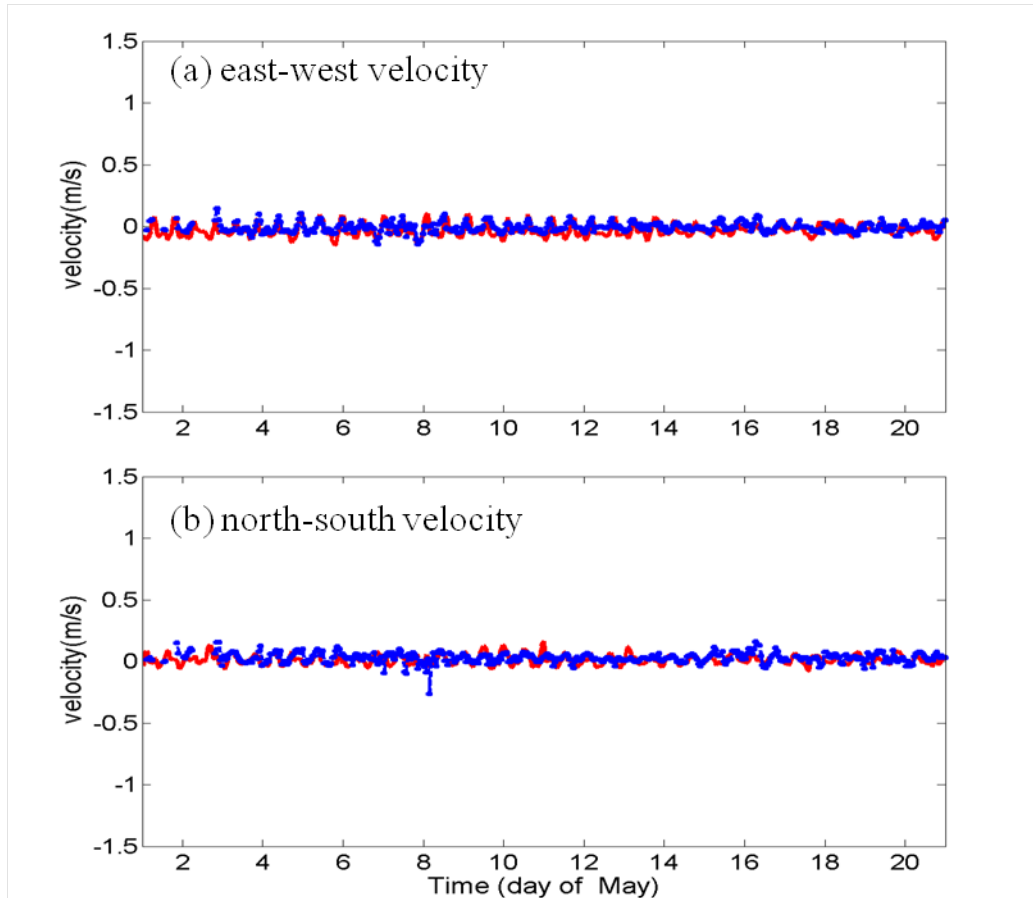
***Figure 5: Comparions of time series of flow velocity in the east-west (a) and north-south (b)
directions between the numerical model results (red curves) and measured data (blue dots) at Sensor
#78, which is located more offshore (see Figure 1). Flow velocity is much weaker and dominated by
wave induced current. Field data is provided in collaboration by S. Elgar and
B. Raubenheimer (WHOI).***

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